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(54) **AUSTENITIC HEAT-RESISTANT ALLOY**

(57) Specific amount of each of C, Si, Mn, P, S, Ni, Cr, Cu, Mo, Nb, Ti, B and N is contained, a specific amount of at least one of Mg and Ca is contained, a total of Nb and Ti is 0.3% or more, and the remainder is Fe and unavoidable impurities. A cumulative number density of a precipitate whose particle diameter falls within a range of more than 0 nm up to 100 nm is 0.1 to 2.0

Number/ μm^2 , a precipitate particle diameter corresponding to a half of the cumulative number density in a distribution of the cumulative number density and the precipitate particle diameter is 70 nm or less, an average hardness is 160 Hv or less, and a grain size number is 7.5 or more.

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Description

Technical Field

5 [0001] The present invention relates to an austenitic heat-resistant steel.

Background Art

10 [0002] In general, a high-temperature process at a few hundred degrees or higher is employed in energy-related instruments such as boilers, reactors and the like, and a heat-resistant material having an excellent creep strength even in high-temperature environments is needed.

[0003] In order that such a heat-resistant material could exhibit an excellent creep strength in high-temperature environments, there are a method of adding an element capable of dissolving in a solid steel in a high-temperature environment to realize an effect of solute strengthening, a method of adding an element capable of precipitating in a high-temperature environment to form a precipitate in a high-temperature environment thereby realizing an effect of precipitation strengthening, a method of growing crystal grains to be coarse to thereby prevent boundary sliding etc.

15 [0004] Among these, the method of growing crystal grains to be coarse interferes with formation of a Cr_2O_3 protective film and therefore may have a risk of worsening steam oxidation resistance.

[0005] For realizing solute strengthening, the amount of the element to be added must be increased. When the amount of the element to be added is increased, it may have some negative influences on other various basal characteristics than creep strength.

[0006] In addition, when the amount of the added element is large, the material cost may increase and there may be a possibility of detracting from economic efficiency. Accordingly, the method of employing the solute strengthening method for a heat-resistant material could not be said to be desirable as a method of realizing an intended strength.

25 [0007] On the other hand, it is conventional that, according to the method of realizing a precipitation strengthening effect, dislocation movement to be accompanied by deformation can be strongly inhibited and therefore a creep strength can be greatly improved. Here, many heat-resistant members are produced in a process of softening heat treatment, cold working and final heat treatment in that order. In these treatments, in order to form large amounts of precipitates in a practical high-temperature environment or during a creep test, the elements to precipitate in the practical environment or during the creep test must be previously dissolved in solid through high-temperature heating in the final heat treatment followed by rapid cooling. In order that larger amounts of precipitated components could be dissolved in solid, such a final heat treatment must be carried out at a temperature as high as possible, in which, however, crystal grains may grow to be coarse and, as a result, there may be a possibility of a risk of steam oxidation resistance.

35 [0008] Under the situation, Patent Document 1 discloses a method for producing an austenitic stainless steel having a high creep strength, having a fine-grained texture and excellent corrosion resistance, which includes a cold-processing step for an austenitic stainless steel containing one or more of Ti: 0.15 to 0.5% by mass and Nb: 0.3 to 1.5% by mass, wherein the steel is heated at a final softening temperature set to be higher than 1200°C and up to 1350°C, then cooled at a cooling rate of 500°C/hr or more, thereafter cold-worked by 20 to 90%, further thereafter heated at 1070 to 1300°C and at a temperature lower by 30°C or more than the final softening temperature, and processed for final heat treatment for cooling at a cooling rate not lower than air cooling.

40 [0009] The method disclosed in Patent Document 1 is for precipitating only small amounts of a part of the elements to be precipitated in the practical environment or during the creep test in the stage of the above-mentioned final heat treatment to thereby prevent the crystal grains from growing to be coarse by the boundary pinning effect of the precipitates. In other words, in the method disclosed in Patent Document 1, the softening heat treatment temperature before the cold processing is increased by a certain level or more relative to the final heat treatment, so that the difference in the solid solute amount corresponding to the temperature difference is thereby precipitated. In that manner, by specifically designing the two heat treatment temperatures, both improvement of the creep strength by high-temperature heat treatment and formation of a texture containing large quantities of fine crystal grains (fine crystal grain texture) have been realized.

50 Citation List

Patent Document

55 [0010] Patent Document 1: JP-B H05-69885

Summary of Invention

Technical Problem

[0011] However, a production plant for use in practical production has an upper limit temperature. When the softening heat treatment temperature is increased up to the plant upper limit temperature, and when a difference is provided between the two heat treatment temperatures like in the method disclosed in Patent Document 1, the final heat treatment temperature must be set lower than the plant upper limit. However, lowering the final heat treatment temperature may result in reduction in the amount of the precipitate to be formed in a practical environment or during a creep test, and therefore, as a result, there is a possibility that the creep strength could not be fully increased. In particular, the invention disclosed in Patent Document 1 is to realize excellent steam oxidation resistance by providing a fine crystal grain texture and to realize an excellent creep strength by precipitating a small amount of precipitates to provide the boundary pinning effect. However, as described above, it is considered that realizing the pinning effect by lowering the final heat treatment temperature would use forwardly but scarify the precipitates that are to be formed in a practical environment or during a creep test.

[0012] In particular, in a steel material such as KA-SUS321J1HTB steel, KA-SUS321J2HTB steel or the like using Ti as a precipitating element, the presence or absence of fine precipitates of Ti carbides may have a great influence on the high-temperature strength of the steel. Naturally, in these steel materials, the temperature range in which Ti dissolves in solid covers high temperatures, and therefore the softening heat treatment temperature may often reach the upper limit owing to limitations on plants in many cases. Accordingly, for the purpose of providing a temperature difference between the softening heat treatment temperature and the final heat treatment temperature, the final heat treatment temperature must be inevitably lowered, and as the case may be, therefore, the amount of the Ti solute to precipitate in a practical environment or during a creep test could not be secured.

[0013] In consideration as above, in principle, it is presumed that, in conventional techniques, the precipitation strengthening that may be obtained from steel material components could not be sufficiently utilized. Of many heat-resistant members, the creep strength serves as a constraining factor to determine the thickness of the member, and therefore it is considered that, with the increase in the creep strength thereof, the member can be thinned and the cost thereof can be reduced. At present, however, it could hardly be said that an austenitic heat-resistant steel could have a sufficient creep strength, and it may be said that the situation of the steel is such that the thickness reduction could bring about cost reduction thereof.

[0014] On the other hand, when a fine crystal grain texture of an austenitic heat-resistant steel is taken as a premise for maintaining steam oxidation resistance thereof, and when the method disclosed in Patent Document 1 is applied thereto, the final heat treatment temperature must be made low. However, as described above, when the final heat treatment temperature is lowered, the solute amount of the precipitating element lowers. Accordingly, the precipitation strengthening effect could not be maximized, and it may be presumed that the creep strength increasing effect could not be sufficiently expressed.

[0015] The present invention has been made in consideration of the situation as above, and its object is to provide austenitic heat-resistant steel having an excellent creep strength while maintaining a fine crystal grain texture.

Solution to Problem

[0016] Heretofore, a creep strength problem has been solved by specifically noting the solute amount of a precipitating element that depends on the temperature in heat treatment. Therefore, in general, it has been considered that, when the final heat treatment temperature is lowered, the solute amount of a precipitating element may reduce and therefore the amount of fine precipitates that would newly precipitate in a practical environment or during a creep test may reduce to thereby lower the creep strength.

[0017] Given the situation, according to the method disclosed in Patent Document 1, the temperature difference between the softening heat treatment and the final heat treatment is defined to be 30°C or more and a part of elements to be precipitated are made to be precipitated in the final heat treatment to thereby prevent the crystal grains from growing to be coarse. However, as described above, the precipitates to be precipitated according to this operation are the precipitates that should naturally precipitate in a practical environment or during a creep test to contribute toward increasing the creep strength of the steel. Specifically, there is a probability that, of the austenitic stainless steel produced according to the method disclosed in Patent Document 1, the creep strength could not be sufficiently increased by the proportion corresponding to the precipitate formed through precipitation of the precipitating element for preventing the crystal grains from growing to be coarse.

[0018] The present inventors have assiduously studied the possibility whether the precipitates formed in the final heat treatment could directly act on the improvement of the creep strength of steel. As a result, the inventors have found that the precipitates that are formed by controlling the addition amount and the solute amount of the precipitating element

to fall within a specific range and by carrying out the final heat treatment under a specific heat treatment condition where the precipitated grain size and the precipitation amount contained in the steel are defined to fall within a specific range (concretely, by carrying out the final heat treatment at a lower temperature than before) can improve creep strength.

[0019] In other words, the present inventors have found that the precipitates formed through final heat treatment under a specific heat treatment condition can contribute toward improvement of creep strength directly as fine grain precipitates. This finding indicates that the precipitates provide a more excellent creep strength than conventional precipitates that are formed in high-temperature heat treatment, and is beyond the concept of the conventional technology.

[0020] In addition, the inventors have found that, since the final heat treatment is carried out under the above-mentioned specific heat treatment condition (at a lower temperature than before), the fine crystal grain texture can be kept as such and the steam oxidation resistance can be maintained.

[0021] The reason why the good creep strength can be attained even though the final heat treatment is carried out under a specific heat treatment condition (that is, even though the final heat treatment is carried out at a lower temperature than before) would be as follows.

[0022] This time, the present inventors have found that, in an austenitic heat-resistant steel, the precipitates formed through final heat treatment can more effectively prevent creep deformation than the precipitates formed during a creep test. In general, the precipitates formed during a creep test of an austenitic heat-resistant steel are formed along dislocation that is introduced along with deformation. Dislocation concentrates in the vicinity of grain boundaries, and therefore the distribution of the precipitates would be uneven.

[0023] As opposed to this, the precipitates formed in final heat treatment in production of an austenitic heat-resistant steel are formed uniformly in the grains. Accordingly, it is considered that the precipitates formed in the final heat treatment could more efficiently prevent the dislocation movement accompanied by creep deformation throughout the grains from the initial stage of deformation. For these reasons, it is presumed that, when the final heat treatment is carried out under the specific heat treatment condition as mentioned above, a good creep strength can be realized. This finding is beyond the conventional conception of the solute amount of a precipitating element that depends on the temperature of heat treatment.

[0024] The austenitic heat-resistant steel which is achieved based on the above findings and solves the above problems includes: C: 0.05 to 0.16% by mass; Si: 0.1 to 1% by mass; Mn: 0.1 to 2.5% by mass; P: 0.01 to 0.05% by mass; S: 0.005% by mass or less (not including 0% by mass); Ni: 7 to 12% by mass; Cr: 16 to 20% by mass; Cu: 2 to 4% by mass; Mo: 0.1 to 0.8% by mass; Nb: 0.1 to 0.6% by mass; Ti: 0.1 to 0.6% by mass; B: 0.0005 to 0.005% by mass; N: 0.001 to 0.15% by mass; and at least one of Mg: 0.005% by mass or less (not including 0% by mass) and Ca: 0.005% by mass or less (not including 0% by mass), with the remainder being Fe and unavoidable impurities, and a total of a content of Nb and a content of Ti is 0.3% by mass or more, and in the austenitic heat-resistant steel, a cumulative number density of a precipitate whose particle diameter falls within a range of more than 0 nm up to 100 nm is 0.1 to 2.0 Number/ μm^2 , a precipitate particle diameter corresponding to a half of the cumulative number density in a distribution of the cumulative number density and the precipitate particle diameter is 70 nm or less, an average hardness is 160 Hv or less, and a grain size number is 7.5 or more.

[0025] Having the constitution as above, the austenitic heat-resistant steel in the present invention contains steel material components each falling within the above-mentioned range and can be provide with a precipitate that may be formed through final heat treatment under a specific heat treatment condition. The precipitate is so controlled that the diameter of the precipitated particles contained in the steel and the precipitation amount thereof each could fall within a specific range, and the precipitate directly contributes toward improving the creep strength of the steel directly as a fine precipitate after the precipitation. The fine precipitate is, as described above, able to improve more the creep strength than a precipitate formed through precipitation by final heat treatment at a higher temperature as in before. Further, in addition thereto, since the final heat treatment is carried out under a specific heat treatment condition, concretely, at a lower temperature than before, the steel can have a fine grain texture and can have excellent steam oxidation resistance.

[0026] It is preferred that the austenitic heat-resistant steel in the present invention further includes at least one of Zr: 0.3% by mass or less (not including 0% by mass), a rare earth element: 0.15% by mass or less (not including 0% by mass) and W: 3% by mass or less (not including 0% by mass).

[0027] When the austenitic heat-resistant steel in the present invention contains Zr within the above-mentioned range, the high-temperature strength thereof can be improved by precipitation strengthening. When the austenitic heat-resistant steel in the present invention contains the rare earth element within the above-mentioned range, the oxidation resistance of the stainless steel can be improved. Further, when the austenitic heat-resistant steel in the present invention contains W within the above-mentioned range, the high-temperature strength thereof can be improved by solute strengthening.

Advantageous Effects of Invention

[0028] The austenitic heat-resistant steel in the present invention contains steel material components each falling within the above-mentioned range, in which the precipitate is so controlled that the precipitated particle diameter and

the precipitation amount each could fall within a specific range, and therefore the steel can have an excellent creep strength while maintaining a fine crystal grain texture.

Brief Description of Drawing

[0029] [FIG. 1] This is a graph for explaining the obtainment of a precipitated particle diameter corresponding to a half of a cumulative number density in the distribution of the cumulative number density and the precipitate particle diameter. The horizontal axis indicates the precipitated particle diameter (nm), and the vertical axis indicates the cumulative number density (Number/ μm^2).

Description of Embodiments

[Austenitic heat-resistant steel]

[0030] An embodiment of the austenitic heat-resistant steel in the present invention (embodiment of carrying out the present invention) is described in detail hereinafter.

[0031] The austenitic heat-resistant steel of this embodiment contains, as steel material components: C: 0.05 to 0.16% by mass; Si: 0.1 to 1% by mass; Mn: 0.1 to 2.5% by mass; P: 0.01 to 0.05% by mass; S: 0.005% by mass or less (not including 0% by mass); Ni: 7 to 12% by mass; Cr: 16 to 20% by mass; Cu: 2 to 4% by mass; Mo: 0.1 to 0.8% by mass; Nb: 0.1 to 0.6% by mass; Ti: 0.1 to 0.6% by mass; B: 0.0005 to 0.005% by mass; N: 0.001 to 0.15% by mass; and at least one of Mg: 0.005% by mass or less (not including 0% by mass) and Ca: 0.005% by mass or less (not including 0% by mass), with the remainder being Fe and unavoidable impurities, and a total of a content of Nb and a content of Ti is 0.3% by mass or more.

[0032] Preferably, the austenitic heat-resistant steel of this embodiment further contains at least one of Zr: 0.3% by mass or less (not including 0% by mass), a rare earth element: 0.15% by mass or less (not including 0% by mass) and W: 3% by mass or less (not including 0% by mass).

[0033] As can be seen from the above-mentioned steel material components, the austenitic heat-resistant steel of this embodiment is similar to KA-SUS321J2HTB steel using Ti as a precipitating element (18 mass% Cr - 10 mass% Ni - 3 mass% Cu - Ni, Ti steel).

[0034] In the austenitic heat-resistant steel of this embodiment containing the above-mentioned steel material components, the cumulative number density of the precipitate whose particle diameter falls within a range of more than 0 nm up to 100 nm is 0.1 to 2.0 Number/ μm^2 , the precipitate particle diameter corresponding to a half of the cumulative number density in the distribution of the cumulative number density and the precipitate particle diameter is 70 nm or less, the average hardness is 160 Hv or less, and the grain size number is 7.5 or more. In this description, the precipitated particle diameter is one calculated as a circle-corresponding diameter of the precipitated particle (precipitate).

[0035] Here, the reason why the precipitate as so controlled that the precipitated particle size and the precipitation in the steel each fall within a specific range can be formed through final heat treatment under a specific heat treatment condition is as already described hereinabove in the section of Solution to Problem. The above-mentioned average hardness and the grain size number can be controlled by controlling the heat treatment temperature. The specific heat treatment condition and heat treatment temperature will be described hereinafter.

[0036] As described above, the precipitate formed under a specific heat treatment condition contributes toward improving creep strength, as being a fine precipitate. In addition, under a specific heat treatment condition, the crystal grains can keep a fine crystal grain texture. Accordingly, the austenitic heat-resistant steel of this embodiment can be excellent in steam oxidation resistance.

[0037] The steel material components of the austenitic heat-resistant steel of this embodiment and the reason why the precipitated particle diameter and the precipitation amount to be contained in the steel are defined each to fall within a specific range are described below.

[0038] As described above, the austenitic heat-resistant steel of this embodiment is similar to KA-SUS321J2HTB that uses Ti as a precipitating element. In KA-SUS321J2HTB, the steel material components described below each exhibit the effect as described below, and when their content falls outside a predetermined content range, there may occur some inconveniences.

[C: 0.05 to 0.16% by mass]

[0039] C has an effect of forming a carbide to improve high-temperature strength. In this embodiment, for obtaining the effect of improving high-temperature strength, C is contained in an amount of 0.05% by mass or more. However, when the C content is excessive to be more than 0.16% by mass, coarse carbides are formed to fail in improving high-temperature strength.

[0040] The lower limit of the C content is preferably 0.08% by mass, more preferably 0.09% by mass. The upper limit of the C content is preferably 0.15% by mass, more preferably 0.13% by mass.

[Si: 0.1 to 1% by mass]

[0041] Si has a deoxidizing effect in a molten steel and effectively acts for improving oxidation resistance. In this embodiment, for obtaining both the deoxidizing effect and the effect of improving oxidation resistance in a molten steel, Si is contained in an amount of 0.1% by mass or more. However, the case where the Si content is excessive and is more than 1% by mass is unfavorable as often causing embrittlement of the steel material.

[0042] The lower limit of the Si content is preferably 0.2% by mass, more preferably 0.3% by mass. The upper limit of the Si content is 0.7% by mass, more preferably 0.5% by mass.

[Mn: 0.1 to 2.5% by mass]

[0043] Mn has a deoxidizing effect in a molten steel. In this embodiment, for obtaining the deoxidizing effect in a molten steel, Mn is contained in an amount of 0.1 % by mass or more. However, the case where the Mn content is more than 2.5% by mass is unfavorable as promoting growth of carbide precipitates to be coarse.

[0044] The lower limit of the Mn content is preferably 0.2% by mass, more preferably 0.3% by mass. The upper limit of the Mn content is 2.0% by mass, more preferably 1.8% by mass.

[P: 0.01 to 0.05% by mass]

[0045] P has an effect of improving high-temperature strength. In this embodiment, for improving high-temperature strength, P is contained in an amount of 0.01% by mass or more. However, when the P content is excessive to be more than 0.05% by mass, it may detract from weldability.

[0046] The lower limit of the P content is preferably 0.015% by mass, more preferably 0.02% by mass. The upper content of the P content is 0.04% by mass, more preferably 0.03% by mass.

[S: 0.005% by mass or less (not including 0% by mass)]

[0047] S is an unavoidable impurity. When the S content is excessive to be more than 0.005% by mass, it degrades hot processability. In this embodiment, for preventing degradation of hot processability, the S content is limited to be 0.005% by mass or less. The S content is preferably smaller.

[0048] The upper limit of the S content is preferably 0.002% by mass, more preferably 0.001 % by mass.

[Ni: 7 to 12% by mass]

[0049] Ni has an effect of stabilizing an austenitic phase. In this embodiment, for stabilizing the austenitic phase, Ni is contained in an amount of 7% by mass or more. However, when the Ni content is more than 12% by mass, it causes cost increase of the steel material.

[0050] The lower limit of the Ni content is preferably 9% by mass, more preferably 9.5% by mass. The upper limit of the Ni content is preferably 11.5% by mass, more preferably 11% by mass.

[Cr: 16 to 20% by mass]

[0051] Cr has an effect of improving oxidation resistance and corrosion resistance of a steel material. In this embodiment, for improving the oxidation resistance and the corrosion resistance of the steel material, Cr is contained in an amount of 16% by mass or more. However, when the Cr content is more than 20% by mass, the steel material may be thereby embrittled.

[0052] The lower limit of the Cr content is preferably 17.5% by mass, more preferably 18% by mass. The upper limit of the Cr content is preferably 19.5% by mass, more preferably 19% by mass.

[Cu: 2 to 4% by mass]

[0053] Cu has an effect of forming a precipitate in a steel to improve high-temperature strength. In this embodiment, for improving high-temperature strength, Cu is contained in an amount of 2% by mass or more. However, when the Cu content is excessive to be more than 4% by mass, the effect may be saturated.

[0054] The lower limit of the Cu content is preferably 2.5% by mass, more preferably 2.8% by mass. The upper limit

of the Cu content is preferably 3.5% by mass, more preferably 3.2% by mass.

[Mo: 0.1 to 0.8% by mass]

5 **[0055]** Mo has an effect of improving corrosion resistance. In this embodiment, for improving corrosion resistance, Mo is contained in an amount of 0.1% by mass or more. However, when the Mo content is excessive to be more than 0.8% by mass, the steel material may be thereby embrittled.

[0056] The lower limit of the Mo content is preferably 0.2% by mass, more preferably 0.3% by mass. The upper limit of the Mo content is preferably 0.6% by mass, more preferably 0.5% by mass.

10 [Nb: 0.1 to 0.6% by mass]

[Ti: 0.1 to 0.6% by mass]

15 [The total of the Nb content and the Ti content is 0.3% by mass or more.]

[0057] Nb and Ti are, when precipitated as a carbonitride (carbide, nitride or carbonitride), able to improve high-temperature strength. In addition, the precipitate prevents crystal grains from growing to be coarse and promotes Cr diffusion. Owing to Cr diffusion, the elements exhibits an effect of subsidiarily improving corrosion resistance (steam oxidation resistance), and therefore, these can be said to be a part of most important elements in the present invention.

20 **[0058]** In this embodiment, for forming a precipitate of Nb and Ti to improve high-temperature strength and for exhibiting the effect of improving steam oxidation resistance, Nb is contained in an amount of 0.1% by mass or more and Ti is contained in an amount of 0.1% by mass or more. By containing both Nb and Ti, the resultant precipitate can more effectively contribute toward improving high-temperature strength.

25 **[0059]** However, these must be contained in such that the total of the Nb content and the Ti content is 0.3% by mass or more, and if not, a minimum required precipitate amount could not be secured.

[0060] The lower limit of the Nb content is preferably 0.2% by mass. The lower limit of the Ti content is preferably 0.15% by mass. The lower limit of the total of the Nb content and the Ti content is preferably 0.35% by mass.

30 **[0061]** On the other hand, when the Nb content is excessive to be more than 0.6% by mass, and when the Ti content is excessive to be more than 0.6% by mass, the precipitate may grow to be coarse in any case, thereby lowering toughness.

[0062] The upper limit of the Nb content and the Ti content is each preferably 0.4% by mass, more preferably 0.3% by mass.

[B: 0.0005 to 0.005% by mass]

35 **[0063]** B has an effect of promoting formation of an $M_{23}C_6$ -type carbide (where M is a carbide-forming element) to improve high-temperature strength. In this embodiment, for improving high-temperature strength, B is contained in an amount of 0.0005% by mass or more. However, when the B content is excessive to be more than 0.005% by mass, it lowers weldability.

40 **[0064]** The lower limit of the B content is preferably 0.001% by mass, more preferably 0.0015% by mass. The upper limit of the B content is preferably 0.004% by mass, more preferably 0.003% by mass.

[N: 0.001 to 0.15% by mass]

45 **[0065]** N has an effect of improving high-temperature strength by solute strengthening. In this embodiment, for improving high-temperature strength, N is contained in an amount of 0.001% by mass or more. However, when the N content is excessive to be more than 0.15% by mass, it causes formation of coarse Ti nitride and Nb nitride to worsen toughness.

50 **[0066]** The lower limit of the N content is preferably 0.002% by mass, more preferably 0.003% by mass. The upper limit of the N content is preferably 0.08% by mass, more preferably 0.04% by mass.

[At least one of Mg: 0.005% by mass or less (not including 0% by mass) and Ca: 0.005% by mass (not including 0% by mass)]

55 **[0067]** Mg and Ca each act as a desulfurizing/deoxidizing element and have an effect of improving hot processability of a steel material. Depending on the content of S that is contained as an unavoidable impurity, Ca and Mg are preferably contained each in a range of 0.005% by mass or less.

[0068] Preferably, the upper limit of Ca and Mg is 0.002% by mass each.

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[Zr: 0.3% by mass or less (not including 0% by mass)]

[0069] Zr is an optional component and has an effect of improving high-temperature strength by precipitation strengthening. However, when the Zr content is excessive to be more than 0.3% by mass, a coarse intermetallic compound may be thereby formed to lower high-temperature ductility.

[0070] The upper limit of the Zr content is preferably 0.25% by mass.

[0071] However, when Zr is contained, it increases the cost of a steel material, and therefore, the component may be optionally contained.

[Rare earth element: 0.15% by mass or less (not including 0% by mass)]

[0072] Rare earth elements are optional components and have an effect of improving oxidation resistance of stainless steel.

[0073] In other words, when a rare earth element is optionally contained, an oxidation scale can be prevented from forming. However, when the rare earth element content is excessive to be more than 0.15% by mass, grain boundaries may partly dissolve in a high-temperature environment, therefore unfavorably detracting from hot processability.

[0074] The upper limit of the rare earth element content is preferably 0.1% by mass, more preferably 0.05% by mass.

[0075] Here, rare earth elements are one or more elements selected from Sc and Y, and 15 kinds of lanthanoid elements typified by La, Ce and Ne, that is, 17 kinds of elements in total. The rare earth element content is the total content of one or more elements selected from those 17 kinds of elements.

[W: 3% by mass or less (not including 0% by mass)]

[0076] W is an optional component, and has an effect of improving high-temperature strength by solute strengthening. However, when the W content is excessive to be more than 3% by weight, coarse intermetallic compounds are formed to lower high-temperature ductility.

[0077] The upper limit of the W content is preferably 2.5% by mass, more preferably 2.0% by mass.

[0078] The steel material components described above each exhibit the effect as described above, when contained in steel, but at the same time, these cause cost increase. Consequently, the content of each component may be determined depending on the necessary strengthening amount and the acceptable cost thereof.

[The remainder being Fe and unavoidable impurities.]

[0079] The remainder is Fe and other unavoidable impurities. Examples of the other unavoidable impurities include, for example, Al, Sn, Zn, Pb, As, Bi, Sb, Te, Se, In, etc.

[0080] Preferably, the amounts of the unavoidable impurities are as small as possible, and as rough indication thereof, it is recommended that the amount of Al is 0.01% by mass or less, Sn is 0.005% by mass or less, Zn is 0.01% by mass or less, Pb is 0.002% by mass or less, As is 0.01% by mass or less, Bi is 0.002% by mass or less, Sb is 0.002% by mass or less, Te is 0.01% by mass or less, Se is 0.002% by mass or less, and In is 0.002% by mass or less.

[The Average hardness is 160 Hv or less.]

[0081] In addition to the compositional range as specified above, and for securing the solute amount of the element to precipitate in a practical environment or during a creep test, in this embodiment, the average hardness (Vickers hardness) is defined to be 160 Hv or less. When the average hardness is more than 160 Hv, the solute amount of the element to precipitate in a practical environment or during a creep test could not be secured, and if so, therefore, the creep strength lowers. For controlling the average hardness to be 160 Hv or less, for example, the steel is heat-treated at a temperature of 1150°C or higher and then cooled in water to easily attain the numeral range, though depending on the above-mentioned compositional formulation thereof.

[0082] Preferably, the upper limit of the average hardness is 140 Hv. Also preferably, the lower limit of the average hardness is 100 Hv, more preferably 110 Hv.

[0083] The Vickers hardness may be measured, for example, according to JIS Z 2244:2009.

[The cumulative number density of the precipitate whose particle diameter falls within a range of more than 0 nm up to 100 nm is 0.1 to 2.0 Number/ μm^2 .]

[The precipitate particle diameter corresponding to a half of the cumulative number density in the distribution of the cumulative number density and the precipitate particle diameter is 70 nm or less.]

[0084] The cumulative number density of the precipitate whose particle diameter falls within a range of more than 0 nm up to 100 nm is defined to be 0.1 to 2.0 Number/ μm^2 , and the precipitate particle diameter corresponding to a half of the cumulative number density in the distribution of the cumulative number density and the precipitate particle diameter is defined to be 70 nm or less, whereby the creep strength can be enhanced.

[0085] Specifically, regarding the precipitate to form in the final heat treatment, while the amount of the precipitate having a size of 100 nm or less is controlled to be not more than a specific level, the precipitate particle diameter corresponding to a half of the cumulative number density is controlled to be 70 nm or less, that is, the precipitates are kept fine, and accordingly, the creep strength can be thereby enhanced.

[0086] The lower limit of the cumulative number density is preferably 0.3 Number/ μm^2 , more preferably 0.4 Number/ μm^2 .

[0087] The upper limit of the precipitate particle diameter corresponding to a half of the cumulative number density is preferably 60 nm, more preferably 50 nm. The lower limit of the precipitate particle diameter corresponding to a half of the cumulative number density is more than 0 nm.

[0088] A method for measuring the precipitated particle diameter and the cumulative number density is described below.

[The grain size number is 7.5 or more.]

[0089] When the grain size number is 7.5 or more, the metal texture is in a sufficiently fine state, and can be said to be a fine crystal grain texture. Accordingly, the steel of the type can maintain steam oxidation resistance.

[0090] For controlling the grain size number to be 7.5 or more, the steel may be processed for final heat treatment under a specific heat treatment condition to be mentioned below.

[Final heat treatment under specific heat treatment condition]

[0091] For controlling the particle size and the precipitation amount of the precipitated particles contained in steel to fall within a specific range, and for controlling the grain size number to be 7.5 or more, the steel may be subjected to final heat treatment under a condition under which the coarsening factor for the precipitate could be 2000°C·min or less, on the premise of the above-mentioned steel material composition and the hardness range. This "condition under which the coarsening factor for the precipitate could be 2000°C·min or less" is the above-mentioned specific heat treatment condition.

[0092] The coarsening factor for precipitate is an index of indicating the influence of heat on the growth of precipitate to be coarse grains, and is a value calculated by integrating a temperature of 900°C or higher at which the precipitate growth goes on relative to the temperature history during the heat treatment, with respect to time. The coarsening factor must include not only the retention time in heat treatment but also the heating time at 900°C or higher and the cooling time. In this connection, the coarsening factor for a conventional austenitic heat-resistant steel which contains Ti as a precipitating element and whose high-temperature strength has been sufficiently increased, such as KA-SUS321J2HTB steel, is about 3000 to 7000°C·min. As opposed to this, for the austenitic heat-resistant of this embodiment, the coarsening factor is 2000°C·min or less, as described above. As the lower limit of the coarsening factor, it is preferably larger than 473°C·min, more preferably 500°C·min or more, even more preferably 821°C·min. or more.

[0093] When the above-mentioned coarsening factor is satisfied, the highest endpoint temperature and the retention time can be controlled in accordance with the limitations on equipment. Here, for forming a precipitate like in a conventional technique, the precipitating element must be dissolved in solid by carrying out the softening heat treatment at a temperature higher by 30°C or more than in the final heat treatment. Specifically, a temperature lower by 30°C than in the softening heat treatment is the upper limit temperature for the above-mentioned final heat treatment.

[Method for measuring precipitated particle diameter and cumulative number density]

[0094] For judging whether or not the coarsening factor could satisfy the above-mentioned condition, it is necessary to quantify the number density and the size distribution of the precipitate. This can be carried out by taking a microscopic image showing the dispersion of precipitate particles on the cross section of a steel material, and analyzing the image for quantification of the data. The microscopic image may be taken, for example, by photographing the surface of an electrolytically-polished steel material with a scanning electron microscope. In a case where the precipitated particles

are fine, a transmission electron microscope may be used in place of the scanning electron microscope. From the viewpoint of quantification accuracy, it is recommended that at least 200 precipitated particles are quantitatively analyzed, and the data of more than 0 nm to 100 nm are arranged through histogram at intervals of 10 nm.

[0095] Briefly, as in the graph shown in FIG. 1, the cumulative number density (Number/ μm^2) at intervals of 10 nm is plotted on the vertical axis, and the precipitated particle diameter (nm) is on the horizontal axis, in which "the cumulative number density of the precipitate whose particle diameter falls within a range of more than 0 nm up to 100 nm" that is defined in the present invention can be understood from the numerical value falling between 90 nm and 100 nm on the horizontal axis. Regarding "the precipitate particle diameter corresponding to a half of the cumulative number density of the precipitate whose particle diameter falls within a range of more than 0 nm to 100 nm", the case shown in the drawing is referred to. In the drawing, the point between 50 nm and 60 nm and the point between 60 nm and 70 nm are connected to give a line, and the precipitate particle diameter can be understood as the numeral value on the horizontal axis on which the resultant line crosses the line extended from a half of the numeral value falling between 90 nm and 100 nm.

[0096] Of the austenitic heat-resistant steel of this embodiment as described above, the steel material components are defined to fall within the above-mentioned range, and the precipitated particle diameter and the precipitation amount in the steel are defined to fall within a specific range, and therefore the steel can have an excellent creep strength while maintaining a fine crystal grain texture.

[0097] Heretofore, crystal grains have been tried to be refined at the sacrifice of the precipitation amount formed in a practical environment or during a creep test, but in the austenitic heat-resistant steel of this embodiment, the precipitation that has been heretofore sacrificed can be made to contribute toward increasing the creep strength. Accordingly, even in the case where the temperature in heat treatment has an upper limit owing to limitations on equipment, etc., the precipitation strengthening effect can be maximized. Consequently, from an austenitic heat-resistant steel using Ti as a precipitating element therein, a heat-resistant stainless steel whose creep strength is further increased while the fine crystal grain texture thereof is kept as such can be produced. The austenitic heat-resistant steel of this embodiment can have an increased creep strength, and therefore the thickness of a heat-resistant member to be formed of the steel can be thinned more than before, and the present invention can realize cost reduction of heat-resistant members.

Examples

[0098] Next, the contents of the present invention are described concretely with reference to Examples that exhibit the effect of the present invention and Comparative Examples not exhibiting it.

[0099] Various steel materials of steel material components Nos. A to F shown in Table 1 were melted individually in a vacuum melting furnace (VIF) to give ingots of 20 kg each, and each ingot was hot-forged to have a size of 130 mm width x 20 mm thickness.

[0100] Subsequently, this was softened by heat treatment at 1250°C, and cold-rolled to give an original steel material having a thickness of 13 mm. Of the steel materials Nos. A to F shown in Table 1, Nos. A to E are similar to so-called KA-SUS321J2HTB steel, and are steel materials satisfying the chemical component composition defined in the present invention. As opposed to these, No. F is a steel material overstepping the chemical component composition defined in the present invention.

[0101] In Table 1, the numerical values given an underline and expressed by an italic are those not satisfying the requirements in the present invention.

[Table 1]

		Steel Material Component No.					
		A	B	C	D	E	F
	C	0.12	0.14	0.10	0.10	0.13	0.11
	Si	0.35	0.44	0.65	0.54	0.34	0.55
	Mn	1.58	1.44	1.10	1.58	1.80	0.98
	P	0.027	0.032	0.022	0.024	0.025	0.029
	S	0.001	0.004	0.002	0.002	0.001	0.001
	Ni	10.3	9.9	10.9	11.1	11.4	8.2
	Cr	18.8	19.2	18.3	18.2	17.9	19.7

(continued)

		Steel Material Component No.					
		A	B	C	D	E	F
Chemical Component Composition (% by mass)	Cu	3.0	3.3	2.8	2.7	2.9	3.1
	Mo	0.32	0.15	0.23	0.33	0.49	0.29
	Nb	0.22	0.28	0.12	0.17	0.32	<u>0.07</u>
	Ti	0.20	0.25	0.21	0.20	0.18	<u>0.09</u>
	B	0.002	0.002	0.005	0.002	0.003	0.002
	N	0.012	0.008	0.014	0.013	0.006	0.010
	Mg	0.001	<0.001	0.002	0.001	0.001	<0.001
	Ca	<0.001	<0.001	0.001	<0.001	0.001	<0.001
	Nb + Ti	0.42	0.53	0.33	0.37	0.50	<u>0.16</u>
	Others	-	-	W: 0.5	rare earth (Ce): 0.018	Zr: 0.10 rare earth (Ce): 0.012	-
*) In the steel material Nos. A to F, the remainder includes Fe and unavoidable impurities.							

[0102] Each original steel material was heat-treated at a varying heating temperature of 1040 to 1215°C for a varying period of time of 0.5 to 10 minutes to vary the coarsening factor [°C·min] for the precipitate, thereby preparing steel materials of Nos. 1 to 31 shown in Table 2. These steel materials were analyzed for the Vickers hardness thereof, the cumulative number density of the precipitate therein whose particle diameter falls within a range of more than 0 nm up to 100 nm, the precipitate particle diameter corresponding to a half of the cumulative number density in the distribution of the cumulative number density and the precipitate particle diameter, the grain size number, and the creep rupture time, in the manner as mentioned below. The measured results are shown in Table 2 along and the coarsening factors therein.

[0103] In Table 2, the numerical values given an underline and expressed by an italic are those not satisfying the requirements in the present invention.

(1) Vickers hardness [Hv]

[0104] Regarding the Vickers hardness, each steel material of Nos. 1 to 31 was tested in a Vickers hardness test according to JIS Z 2244:2009 to measure the hardness thereof. The load in the Vickers hardness test was 10 kg. Those having a Vickers hardness of 160 Hv or less were evaluated as excellent in average hardness, while those more than 160 Hv were evaluated as poor in average hardness.

(2) Cumulative number density of precipitate whose particle diameter falls within a range of more than 0 nm up to 100 nm [$\mu\text{m}/\text{cm}^2$]

(3) Precipitate particle diameter corresponding to a half of the cumulative number density in the distribution of the cumulative number density and the precipitate particle diameter [μm]

[0105] For the cumulative number density (2) and the precipitate particle diameter corresponding to a half of the cumulative number density (3), a picture of the surface of each steel material that had been electrolytically polished was taken using a scanning electron microscope at a magnification of 6000 times, at least 200 or more precipitated particles were analyzed on the image, and from the resultant data, a graph as shown in FIG. 1 was drawn, in which the distribution of the cumulative number density and the precipitate particle diameter was calculated.

[0106] At this time, an image in which substances of 20 nm in size could be recognized at a magnification of 6000 times was obtained, and in this Example, it was confirmed that any other finer precipitates than those did not exist in the image by the use of a transmission electron microscope.

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(4) Grain size number

[0107] For the grain size number, the texture of the steel material of Nos. 1 to 31 was microscopically observed according to JIS G 0551:2013 to measure the crystal grain number. Those having a crystal grain number of 7.5 or more were considered as having passed the test, while those with less than 7.5 were considered as having failed in the test.

(5) Creep rupture time [hr]

[0108] Regarding the creep rupture time, a test piece was prepared from each steel material of Nos. 1 to 31 according to JIS Z 2271:2010, and tested to measure the time. Those having taken a creep rupture time of 650 hours or more were evaluated as excellent in creep strength, while those with less than 650 hours were evaluated as poor in creep strength.

[Table 2]

No.	Steel material component No.	Coarsening factor (°C·min)	Vickers hardness (Hv)	Cumulative number density of precipitate whose particle diameter falls within a range of more than 0 nm up to 100 nm (Number/ μm^2)	Precipitate particle diameter corresponding to a half of the cumulative number density of precipitate whose particle diameter falls within a range of more than 0 nm up to 100 nm (nm)	Grain size number	Creep rupture time (hr)	Remarks 1	Remarks 2
1	A	3534	128	<u>0.010</u>	<u>84</u>	<u>6.5</u>	819	Comparative Example	*1
2	A	2519	132	<u>0.039</u>	<u>78</u>	<u>7.0</u>	705	Comparative Example	*1
3	A	2381	136	0.118	<u>73</u>	7.5	<u>613</u>	Comparative Example	
4	A	1742	146	0.227	68	8.0	687	Example	
5	A	1343	152	1.309	44	8.5	702	Example	
6	A	4774	143	<u>0.036</u>	<u>74</u>	7.5	<u>576</u>	Comparative Example	
7	A	1603	144	0.395	52	8.5	656	Example	
8	A	866	139	0.487	50	8.5	693	Example	
9	A	473	<u>167</u>	1.251	46	8.0	<u>337</u>	Comparative Example	*2
10	B	2476	127	0.109	<u>85</u>	7.5	<u>636</u>	Comparative Example	
11	B	1612	130	0.165	65	8.0	701	Example	
12	B	1434	139	0.596	47	8.5	745	Example	
13	B	4598	139	<u>0.055</u>	<u>77</u>	7.5	<u>610</u>	Comparative Example	
14	B	1577	141	0.414	56	8.5	668	Example	
15	C	2316	145	<u>0.089</u>	<u>77</u>	7.5	<u>596</u>	Comparative Example	
16	C	1576	139	0.145	61	7.5	683	Example	

(continued)

No.	Steel material component No.	Coarsening factor (°C-min)	Vickers hardness (Hv)	Cumulative number density of precipitate whose particle diameter falls within a range of more than 0 nm up to 100 nm (Number/ μm^2)	Precipitate particle diameter corresponding to a half of the cumulative number density of precipitate whose particle diameter falls within a range of more than 0 nm up to 100 nm (nm)	Grain size number	Creep rupture time (hr)	Remarks 1	Remarks 2
17	C	1879	142	0.106	68	7.5	661	Example	
18	C	1083	153	0.418	51	8.0	685	Example	
19	D	5846	125	<u>0.013</u>	<u>92</u>	<u>6.0</u>	823	Comparative Example	*1
20	D	1941	129	0.126	68	7.5	669	Example	
21	D	1698	129	0.194	56	7.5	703	Example	
22	D	4633	143	<u>0.045</u>	<u>81</u>	7.5	<u>582</u>	Comparative Example	
23	D	821	135	0.341	49	8.0	673	Example	
24	E	2943	122	<u>0.077</u>	<u>91</u>	<u>6.0</u>	794	Comparative Example	*1
25	E	1758	127	0.372	65	7.5	674	Example	
26	E	1661	131	0.422	50	8.0	703	Example	
27	E	2093	141	0.262	<u>73</u>	7.5	<u>630</u>	Comparative Example	
28	E	935	138	0.674	49	8.0	691	Example	
29	F	1858	125	<u>0.021</u>	67	<u>6.5</u>	<u>617</u>	Comparative Example	*3
30	F	1137	133	<u>0.065</u>	52	<u>7.0</u>	<u>573</u>	Comparative Example	*3

(continued)

No.	Steel material component No.	Coarsening factor (°C·min)	Vickers hardness (Hv)	Cumulative number density of precipitate whose particle diameter falls within a range of more than 0 nm up to 100 nm (Number/ μm^2)	Precipitate particle diameter corresponding to a half of the cumulative number density of precipitate whose particle diameter falls within a range of more than 0 nm up to 100 nm (nm)	Grain size number	Creep rupture time (hr)	Remarks 1	Remarks 2
31	F	697	146	<u>0.087</u>	44	7.5	<u>495</u>	Comparative Example	*3

*1 in Remarks 2 indicates that, in the steel material, the crystal grains grew coarsely.
 *2 in Remarks 2 indicates that the Vickers hardness was low and the steel material could not secure the solute amount.
 *3 in Remarks 2 indicates that the steel material was outside the definition in the present invention.

[0109] As shown in Table 2, it was confirmed that the steel materials of Nos. 4, 5, 7, 8, 11, 12, 14, 16, 17, 18, 20, 21, 23, 25, 26 and 28 that exhibited the desired effects in the present invention took a creep rupture time of 650 hours or more, and all the materials had a creep rupture strength more excellent than the comparative examples. In addition, it was confirmed that all these steel materials of Nos. 4, 5, 7, 8, 11, 12, 14, 16, 17, 18, 20, 21, 23, 25, 26 and 28 contained fine crystal grains (that is, these had a fine crystal grain texture) (all in Examples).

[0110] It is presumed that these Examples having a fine crystal grain texture can have good steam oxidation-resistant characteristics.

[0111] In particular, Nos. 4 and 7, Nos. 11 and 14, Nos. 16 and 18, Nos. 20 and 23, and Nos. 25 and 28 are Examples in which the heat treatment temperature for the former was lower than that for the latter. Concretely, Nos. 4 and 7, Nos. 11 and 14, and Nos. 25 and 28 are Examples in which the temperature was lowered by 20°C; Nos. 16 and 18 are Examples in which the temperature was lowered by 10°C; and Nos. 20 and 23 are Examples in which the temperature was lowered by 30°C.

[0112] Among these, from the results of Nos. 16 and 18, Nos. 20 and 23, and Nos. 25 and 28, it is found that the latter number sample took a longer creep rupture time as compared with the former number sample that was heat-treated at a higher temperature. This finding indicates a possibility that the creep strength enhancing effect realized in the present invention would differ from the effect in the conventional knowledge that notes the solute amount of a precipitating element and means that "a higher heat treatment temperature gives the higher creep strength".

[0113] On the other hand, as shown in Table 2, the steel materials of Nos. 1, 2, 19 and 24 are Comparative Examples in which the crystal grains grew coarsely since the heat treatment condition (the precipitate coarsening factor) was inappropriate. Specifically, these steel materials could not realize even a fine crystal grain texture that was attained according to a conventional technique (for example, in the invention described in Patent Document 1). Consequently, it is presumed that the steel materials of Nos. 1, 2, 19 and 24 could not obtain good moisture oxidation-resistant characteristics.

[0114] The steel material of No. 9 is Comparative Example in which the precipitate coarsening factor of the material was too low, and therefore the precipitated component could not be sufficiently dissolved in solid. The steel material of No. 9 had a fine crystal grain texture, but it was confirmed that the Vickers hardness (average hardness) thereof was outside the definition in the present invention, and the creep rupture time was short.

[0115] The steel materials of Nos. 29 to 31 are Comparative Examples in which the chemical component compositions are outside the definition in the present invention.

[0116] Of those, in the steel materials of Nos. 29 and 30, the crystal grains were coarse and contained some favorable element in point of creep strength, but for the creep strength of both the steel materials, the time was shorter than 650 hours, that is, as compared with Examples, the steel materials could have only an insufficient strength.

[0117] The steel material of No. 31 had a grain size number of 7.5 and had a good fine crystal grain texture, but for the creep strength thereof, the time was shorter than 650 hours, that is, as compared with Examples, the steel material could have only an insufficient strength.

[0118] The steel materials of Nos. 3, 6, 10, 13, 15, 22 and 27 had a good fine crystal grain texture having a grain size number of 7.5 or more. However, these steel materials of Nos. 3, 6, 10, 13, 15, 22 and 27 could not satisfy at least one of the cumulative number density of the precipitate whose particle diameter falls within a range of more than 0 nm up to 100 nm, and the precipitate particle diameter corresponding to a half of the cumulative number density in the distribution of the cumulative number density and the precipitate particle diameter, and therefore, as compared with Examples, these were poor in point of the creep rupture time (all Comparative Examples).

[0119] From the above, it was confirmed that the steel materials satisfying the definition in the present invention (the steel materials of Examples) were excellent in creep strength in point of having a fine crystal grain texture as compared with the steel materials not satisfying the definition in the present invention (the steel materials of Comparative Examples).

[0120] While the present invention has been described in detail and with reference to specific embodiments thereof, it will be apparent to one skilled in the art that various changes and modifications can be made therein without departing from the spirit and scope thereof.

[0121] The present application is based on a Japanese Patent Application No. 2014-042889 filed on March 5, 2014, the contents of which are herein incorporated by reference.

Industrial Applicability

[0122] The austenitic heat-resistant steel in the present invention exhibits an excellent creep strength even in a high-temperature environment, and is therefore useful for energy-related instruments such as boilers, reactors and the like. The steel has an excellent creep strength even in a high-temperature environment.

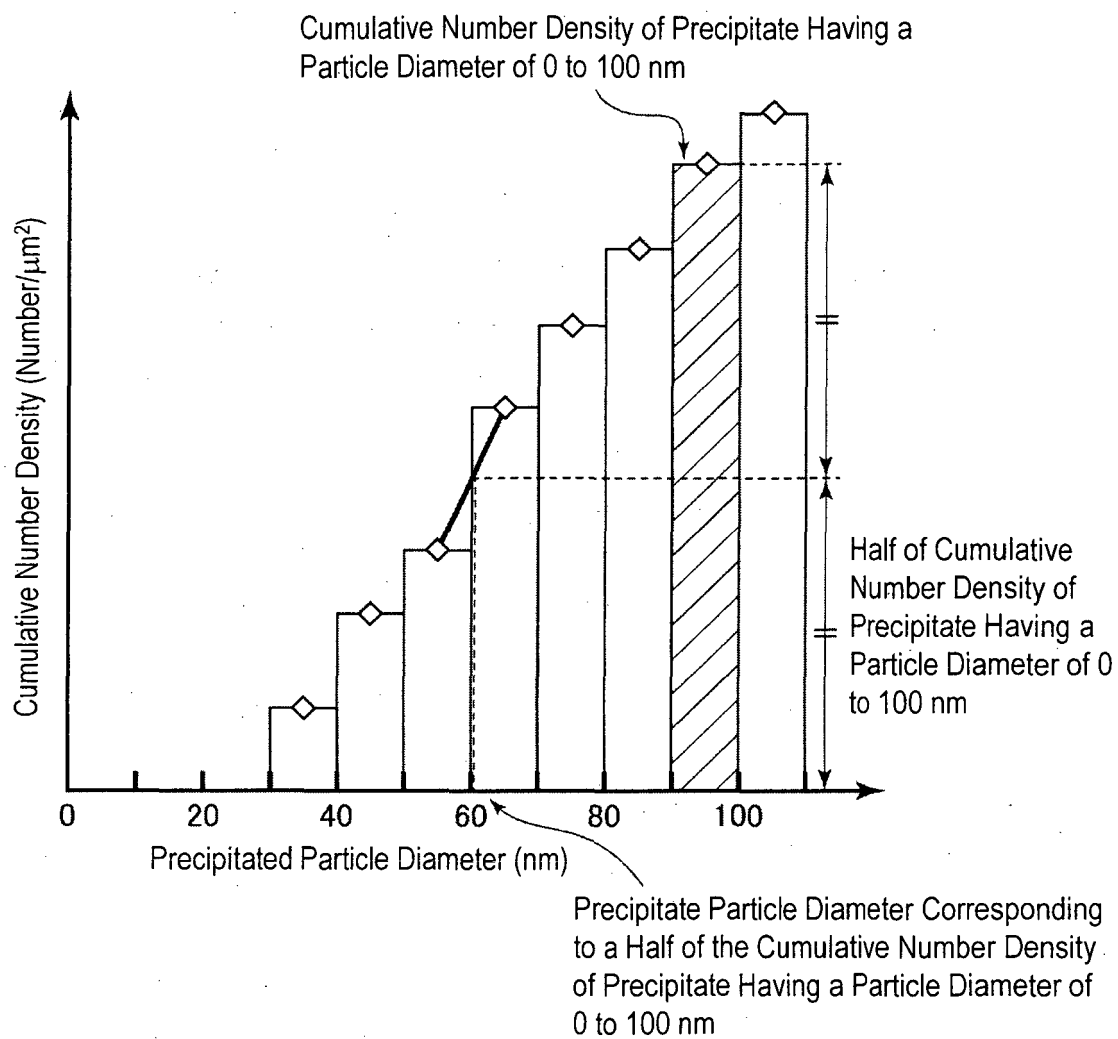
Claims**1.** An austenitic heat-resistant steel, comprising:

C: 0.05 to 0.16% by mass;
 Si: 0.1 to 1% by mass;
 Mn: 0.1 to 2.5% by mass;
 P: 0.01 to 0.05% by mass;
 S: 0.005% by mass or less (not including 0% by mass);
 Ni: 7 to 12% by mass;
 Cr: 16 to 20% by mass;
 Cu: 2 to 4% by mass;
 Mo: 0.1 to 0.8% by mass;
 Nb: 0.1 to 0.6% by mass;
 Ti: 0.1 to 0.6% by mass;
 B: 0.0005 to 0.005% by mass;
 N: 0.001 to 0.15% by mass; and
 at least one of Mg: 0.005% by mass or less (not including 0% by mass) and Ca: 0.005% by mass or less (not including 0% by mass), with the remainder being Fe and unavoidable impurities,

wherein a total of a content of Nb and a content of Ti is 0.3% by mass or more,
 a cumulative number density of a precipitate whose particle diameter falls within a range of more than 0 nm up to 100 nm is 0.1 to 2.0 Number/ μm^2 ,
 a precipitate particle diameter corresponding to a half of the cumulative number density in a distribution of the cumulative number density and the precipitate particle diameter is 70 nm or less,
 an average hardness is 160 Hv or less, and
 a grain size number is 7.5 or more.

2. The austenitic heat-resistant steel according to claim 1, further comprising at least one of Zr: 0.3% by mass or less (not including 0% by mass), a rare earth element: 0.15% by mass or less (not including 0% by mass) and W: 3% by mass or less (not including 0% by mass).

FIG. 1



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2015/056433

A. CLASSIFICATION OF SUBJECT MATTER

C22C38/00(2006.01)i, C21D6/00(2006.01)i, C21D8/02(2006.01)i, C22C38/58(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C22C38/00-38/60, C21D6/00, C21D8/02

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho 1922-1996 Jitsuyo Shinan Toroku Koho 1996-2015
Kokai Jitsuyo Shinan Koho 1971-2015 Toroku Jitsuyo Shinan Koho 1994-2015

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2013-133533 A (Kobe Steel, Ltd.), 08 July 2013 (08.07.2013), steel type N & WO 2013/099639 A1 & US 2014/0356641 A1 & EP 2799570 A1 & VN 39631 A & CN 104024459 A & KR 10-2014-0094023 A	1, 2
A	JP 9-165655 A (NKK Corp.), 24 June 1997 (24.06.1997), claims (Family: none)	1, 2
A	JP 2005-281855 A (Daido Steel Co., Ltd.), 13 October 2005 (13.10.2005), claims & US 2005/0194073 A1 & EP 1577414 A2	1, 2

☐ Further documents are listed in the continuation of Box C.

☐ See patent family annex.

* Special categories of cited documents:

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"&" document member of the same patent family

Date of the actual completion of the international search
01 June 2015 (01.06.15)

Date of mailing of the international search report
09 June 2015 (09.06.15)

Name and mailing address of the ISA/
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3-4-3, Kasumigaseki, Chiyoda-ku,
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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP H0569885 B [0010]
- JP 2014042889 A [0121]